

FINAL TECHNICAL REPORT

covering the period June 1974 through September 1974

NASA Grant No. NSG 7030

Very Long Baseline Interferometry Using
a Communication Satellite

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Principal Investigator

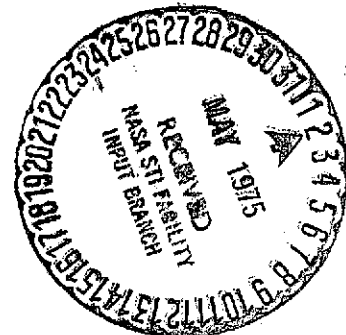
(NASA-CR-142667) VERY LONG BASELINE
INTERFEROMETRY USING A COMMUNICATION
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(The NASA Technical Officer for this grant is J. D. Rosendhal,
Code SGA, NASA Headquarters, Washington, DC.)

This grant was made to permit the principal investigator to participate in a program involving the use of an experimental communication satellite as an aid to very-long-baseline interferometry. The role of the principal investigator is that of coordinator or chairman of the working committee involved in the experiment. The grant funds were used for travel and communications in conjunction with the work of the committee.

The committee consists of the following persons:

G. W. Swenson, Jr.	--	University of Illinois
J. L. Yen	--	University of Toronto
K. I. Kellermann	--	National Radio Astronomy Observatory
Benno Rayhrer	--	National Radio Astronomy Observatory
S. H. Knowles	--	Naval Research Laboratory
W. B. Waltman	--	Naval Research Laboratory
N. W. Broten	--	National Research Council (Canada)
D. N. Fort	--	National Research Council (Canada)

The tasks of the experiment have been divided among the various institutions represented on the committee as follows:

National Radio Astronomy Observatory: Design and construction of the 250 millisecond, 10 MHz bandwidth delay line; design and construction of real-time correlator.

University of Toronto: Design and construction of modem for communication link.

National Research Council: Software for Algonquin Park computer, for delay computation, real-time data processing.

Naval Research Laboratory: Design and construction of transmitter and receiver for satellite communication link.

University of Illinois: Technical coordination and interfacing; committee administration.

Coordination meetings have been held in Charlottesville, Virginia; Toronto, Ontario; and Urbana, Illinois. The status of the project on February 1, 1975 is indicated in Appendix A of this report. Subsequent to that date it has been learned that additional time on the satellite will probably be available from the NASA allocation in "non-prime" time (weekends and nights).

A paper describing the experiment was read (by the principal investigator) at the Fall Scientific Meeting of the U.S. National Committee of the International Union of Radio Science in Boulder, Colorado on October 16, 1974. An abstract is included here as Appendix B.

The general outline of the experiment is given in Appendix C. No changes have been made in this outline during the period of this report.

All funds in the grant have been expended. As these funds were inadequate to cover the expenses of the project during the grant period, the balance has been paid from personal funds of the principal investigator.

The program is continuing.

Progress Report - CTS Satellite VLB Interferometer Project

Date: February 1, 1975

1. Status of the project on this date:

A. Participants -

1. University of Toronto (J. L. Yen)
2. University of Illinois, Urbana (G. W. Swenson, Jr.)
3. National Radio Astronomy Observatory (U.S.A.)
(K. I. Kellermann and B. Rayhrer)
4. Naval Research Laboratory (U.S.A.) (S. H. Knowles and
W. B. Waltman)
5. National Research Council (Canada) (N. W. Broten and
D. Fort)

B. Availability of Time on the CTS Satellite:

An allocation of time sufficient to perform the minimal experiment has been granted by the Canadian authorities (DOC) from their share of the satellite's schedule. A proposal was submitted to the U.S. authorities (NASA) one year ago for equal time from the U.S. allocation, but to date there has been no response.

C. Schedule of Experiment: As of this date, it is understood that the satellite launching is expected at the end of 1975.

2. Progress reports:

A. National Radio Astronomy Observatory (Benno Rayhrer)

The delay line and correlator are under development at the Charlottesville, Va. laboratory. The design for the master Delay Card has been completed and a wire-wrap prototype has been tested. Fabrication is under way commercially.

The digital fringe rotator has been completed. The Buffer and associated control logic are under construction.

All hardware for the delay line and correlator were on hand in November, 1974. Semiconductors and circuit components were ordered in January, 1975 and delivery is expected in mid-February.

The Buffer memory and parallel-to-serial converter are under construction and the serial-to-parallel converter is under design.

B. Naval Research Laboratory (W. B. Waltman)

The 20-watt Ku-band travelling wave tube was overdue in early December, but delivery was expected that month. Other components were to have been ordered in December, 1974.

C. National Research Council (N.W. Broten)

Cables for interconnecting the telescopes at Algonquin Park were ordered in December, 1974. No other long-lead-time hardware items are involved in NRC's contributions.

N. W. Broten attended a CTS experimenters' meeting in November, 1974.

Work on the sampler had not been started as of December 1, and little work had been done on the software.

D. University of Toronto (J. L. Yen)

The Modem has been bench-tested under no-noise conditions, and works satisfactorily. Circuit components have been ordered and are expected in February. It remains to design circuit-board layouts and to test the system with added noise. A block diagram is appended.

J. L. Yen attended the experimenters' meeting in November, 1974.

reported by G. W. Swenson, Jr.
University of Illinois
Observatory
Urbana, Illinois 61801

APPENDIX B

Paper presented at the 1974 Annual Meeting, U. S. National Committee for URSI, Boulder, Colorado, October 16, 1974.

3-8 VERY LONG BASELINE INTERFEROMETRY USING AN EARTH SATELLITE: G.W. Swenson, Jr., University of Illinois, Urbana, Illinois; J.L. Yen, University of Toronto, Toronto, Ontario; N.W. Broten and D. Fort, National Research Council, Ottawa, Ontario; K.I. Kellermann, and B. Rayhrer, National Radio Astronomy Observatory, Green Bank, West Virginia; S.H. Knowles, Naval Research Laboratory, Washington, DC.

An experiment in long-baseline interferometry is planned, using the Communication Technology Satellite to transmit the base-band "signal" from one telescope to the other for real-time correlation. A 20 megabit data rate is planned, calling for a delay-line of 10 MHz bandwidth and controllable delay up to 275 milliseconds. A number of sources will be studied on baselines from Ontario to West Virginia and California.

APPENDIX C

Title: SATELLITE-LINK RADIO INTERFEROMETRY

Sponsoring Organizations:

University of Toronto,
University of Illinois at Urbana-Champaign,
National Research Council (Canada),
U.S. Naval Research Laboratory,
National Radio Astronomy Observatory (U.S.A.)

Experiment Leaders:

J. L. Yen (University of Toronto)
G. W. Swenson, Jr. (University of Illinois, Urbana)

Associated Experiment Leaders:

K. I. Kellermann (National Radio Astronomy Observatory)
N. W. Broten (National Research Council)
S. H. Knowles (U.S. Naval Research Laboratory)
Benno Rayhrer (National Radio Astronomy Observatory)
David Fort (National Research Council)

Objectives:

- a. The purposes of the experiment are twofold: (1) To explore the use of the satellite as a communication link in long-baseline radio interferometry, to permit real-time correlation of data from two widely-separated radio telescopes; and (2) To perform original investigations of the structure and variability of cosmic radio sources.
- b. The communications satellite promises to supply the solution to a major current problem in radio astronomy: how to extend the principle of the long-baseline radio interferometer to permit the full mapping of very small and very distant radio sources. The solution of this problem will make possible major advances in man's understanding of the Universe and has implications for future research in geophysics, particularly in plate tectonics, seismology, and geodesy.

c. Successful use of the satellite in this experiment would point the way to organization of a continent-wide or global radio telescope, utilizing many radio telescopes as well as one or more communication satellites. It would also permit improvement of the precision of current measurements of cosmic source-positions and of baseline lengths between radio telescopes.

d. Present long-baseline interferometer practice utilizes broadband magnetic tape recording to permit correlation of data from two or more widely-separated radio telescopes. Even with only two telescopes (one baseline) there are formidable logistical problems involved in the recording, shipping, and playback of the large quantities of magnetic tape required. The few experiments that have been conducted involving three or four telescopes (up to six baselines) have demonstrated that this technique is quite unsatisfactory for multiple baseline interferometry. Real-time, simultaneous correlation of the telescopes comprising all baselines in an observation is greatly to be desired, but this would require instantaneous communication of the broadband outputs of all telescopes to a common location. The geostationary communication satellite promises a solution to this problem.

e. The goals of the experiment are as follows:

- 1) To investigate the feasibility of using a geostationary communication satellite to permit real-time correlation of the broad-band data outputs from two widely-separated radio telescopes.
- 2) To investigate the structure and its variability of a number of extragalactic radio sources, at resolution from 10^{-2} to 10^{-4} seconds of arc.

Experiment Plan:

Brief description: Several observing sessions will be conducted, depending on the availability of the satellite. During each session two telescopes will observe the same cosmic source and the broadband output of one telescope will be transmitted (by auxiliary antennas at the observatories) to the other observatory via the satellite. Here they will be combined (correlated) in real time to obtain the output "fringes" of the interferometer. The experiment will be begun with a relatively short baseline, from Algonquin Park, Ontario to Green Bank, West Virginia. After the techniques have been demonstrated, the Owens Valley, California telescope will be substituted for the West Virginia telescope for additional observations. The "fringes" will then be studied by the astronomers to infer information about the structure of the cosmic sources under investigation. Concurrently, at least in initial phases of the program, conventional tape-recorded observations will be carried out simultaneously over the same baselines in order to compare the results obtained by the two different techniques.

Pre Experiment Tasks.

(a) Equipment required: A suitable antenna for transmitting to or receiving from the satellite is needed at each observatory. A 10-meter antenna is available at Algonquin Radio Observatory and 25-meter antennas are available at NRAO (West Virginia) and OVRO (California). Suitable transmitting and receiving equipment will be built by the experimenters in their in-house facilities. A controllable, broadband (20 MBs) delay line with 250 ms delay is needed, as well as digitization and correlation equipment. These will be designed and procured by the experimenters. The radio

telescopes and their associated receivers, on-line computers and timing equipment are already available in suitable form for the experiment.

(b) Interface requirements: A modulator is needed at the transmitter and a demodulator at the receiver end of the satellite communication link. These will be designed and procured by the experimenters, along with the transmitter and receiver themselves.

(c) Software: Additional software is required for formatting the data, and controlling the delay line. This will be written and debugged by the experimenters for existing computers.

Background.

Long-baseline radio interferometry is an extremely important, current development in radio astronomy. It utilizes two radio telescopes, separated by great distances, which simultaneously observe the same cosmic radio source. The output "signals" from the two radio telescopes are then multiplied together in a "correlator", whose output constitutes the experimental data. The correlator output is equivalent to the fringes produced by the Michelson interferometer of optics, and, at a given instant of time, is one component of the Fourier transform of the spatial brightness-distribution of the cosmic radio source.

Short-baseline interferometers, whose constituent telescopes are near one another, can be connected by coaxial cables to transmit their respective outputs to the correlator. Similarly, cables can be used to distribute the necessary phase-coherent reference-oscillator signals to the telescopes. With baselines of hundreds of thousands of kilometers, however, the output "signals" must be

recorded on magnetic tape at each station and later transported to a common place for correlation. Reference oscillator signals, in this case, must be supplied by "independent" local oscillators at the respective stations.

Extreme stability of phase and frequency are necessary in the local oscillators, which must be synchronized with great precision. The use of magnetic tape recorders severely limits the radio-frequency band-width and imposes great logistical burdens on the observers.

The long-baseline interferometer has made possible enormous advances in astronomical research by virtue of its capability for resolving extremely small structure in cosmic sources. The best-sited optical telescopes can resolve source details on the order of 0.3 arc-seconds under the best atmospheric conditions. By contrast, interferometers using independent local oscillators and intercontinental baselines have resolved radio-source structure as small as 10^{-4} arc-seconds. It can be predicted that the long-baseline radio-interferometer will eventually produce important advances in geodesy and plate-tectonics, as well, by virtue of its ability to measure large distances with very great precision.

The potentially-greatest contribution of the long-baseline interferometer to astronomy will come when it is able to map the details of very small cosmic radio sources. At each instant, the interferometer yields one component of a Fourier series representing the source brightness distribution. By utilizing many telescopes, and thus many baselines, it is possible to produce enough data to permit the brightness to be determined. This is an

established technique of short-baseline interferometry. "Aperture Synthesis" radio telescopes are in regular use for mapping radio sources to resolutions of a few arc-seconds. These telescopes consist of groups of antennas interconnected by coaxial cables. In the long-baseline case, however, the necessary phase synchronization for full source-synthesis has not been achieved on continental baselines. Furthermore, the use of magnetic-tape recording in a multiple-antenna synthesis scheme promises logistical and data-processing problems of great magnitude. It is doubtful that much success will ever be achieved in synthesis of sources at resolutions better than 10^{-2} arc seconds, using independent local oscillators and magnetic-tape recording.

What is needed is a real-time communications system, capable of transmitting several signals of, say, 10 MHz bandwidth in real time from widely-spaced telescopes to a central processing location. If this can be accomplished, radio astronomy will again make revolutionary contributions to man's understanding of the universe.

The communication satellite presents an apparently feasible solution to this problem.

Several major radio telescopes are available for this experiment, including the 150-foot telescope of the Algonquin Radio Observatory (National Research Council), the 140-foot telescope of the National Radio Astronomy Observatory, and the 130-foot telescope of the Owens Valley Radio Observatory of the California Institute of Technology. These instruments routinely work together as long-baseline interferometers, using magnetic-tape recording of telescope output and completely independent local-oscillators. The purpose of

of these observations is to determine the structure of certain complex, extra-galactic radio sources.

The signal from each telescope will be digitized, probably in one-bit fashion. One telescope's output will be transmitted to the satellite via the local ground terminal. The satellite will retransmit the bit stream to the other observatory where the signals will be delay-equalized and correlated under the control of a computer. The correlator and delay-register will be specially-constructed for this purpose. Output from the correlator will be recorded on digital magnetic tape for further processing by general-purpose computer.